Tyler Thorsen

Norman Loeb, Seiji Kato, Fred Rose

Closure and attribution of the observed variability in the Earth's energy budget

Introduction

- CERES can provide observations of the total TOA energy budget, but isolating individual contributions must rely on bottom-up calculations based on cloud, surface, and atmospheric inputs.
  - Such a decomposition can provide valuable insights into the into the underlying causes of observed changes in the radiation budget.
  - Relating the individual radiative responses observed on short time scales to those from long-term climate change is worthwhile but challenging.

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  - Such a decomposition can provide valuable insights into the into the underlying causes of observed changes in the radiation budget.
  - Relating the individual radiative responses observed on short time scales to those from long-term climate change is worthwhile but challenging.
- First, it is prudent to understand how accurately one can attribute the total variability in the energy budget to the underlying individual radiative anomalies.
- **Extend the analyses of Thorsen et al. (2018) to explore how best to decompose and reproduce the observed EBAF-TOA anomalies over the past 2 decades.**

Thorsen et al. 2018

- Applied partial radiative perturbation (PRP) calculations to observations
- The impact of a perturbation Δx on the flux ($\delta F_{\Delta x}$):

$$\delta F_{\Delta x} = F(x + \Delta x, y_1, ..., y_N) - F(x, y_1, ..., y_N)$$

  - Fluxes (F) computed with gridded month mean inputs $x, y_1, ..., y_N$ (Fu-Liou)
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  ❺ Insolation and trace gases (ozone, carbon dioxide, methane, nitrous oxide, CFC-11, CFC-12, HCFC-22),
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- Sum ❻+❼+❽ = total impact of cloud anomalies $\delta F^{PRP}_{\Delta cld}$: "pure PRP approach" for isolating cloud radiative impact

Adjusted CRE approach

- Alternative to the pure PRP approach, the impact of clouds can be isolated by adjusting the cloud radiative effect (CRE, the difference in the all-sky and clear-sky radiative flux) for the masking effects of non-cloud variables (Soden et al. 2008):

$$\delta F^{CRE}_{\Delta cld} = \Delta CRE^{EBAF} - \sum_i \left[\delta F_{x_i}(\text{all-sky}) - \delta F_{x_i}(\text{clear-sky})\right]$$

  - ΔCRE^{EBAF}: monthly gridded deseasonalized CRE anomalies from EBAF-TOA
  - δF_{x_i}(all-sky) and δF_{x_i}(clear-sky) are the non-cloud PRP calculations

Input datasets

- 1 degree gridded monthly mean data from March 2000 through March 2020
- Non-cloud properties: GEOS-5.4.1 (temperature, water vapor, ozone), MATCH/MODIS (aerosols), AIRS L3 (CO2, CH4), NOAA ESRL (N2O, CFCs), CERES SAH (surface albedo), SORCE (insolation)

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- Also explore using a "tuned" set of inputs from the EBAF-surface algorithm
  - Produces 2 optimized sets of cloud, surface, and atmospheric inputs: (1) those tuned to all-sky EBAF-TOA fluxes, (2) those tuned to clear-sky EBAF-TOA fluxes

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- Using these tuned inputs in our PRP calculations will presumably provide a more accurate decomposition of the EBAF-TOA variability
  - Highly under-constrained problem: possible to not find the optimal solution, uncorrected biases $\rightarrow$ insight from PRP calculations.

Comparisons to EBAF-TOA

- Comparisons to EBAF Ed4.1 TOA data: absorbed solar radiation (ASR), longwave (LW) radiation, and net (ASR+LW). TOA fluxes are defined positive downwards (LW = -OLR)
- EBAF-TOA anomaly time series compared to bottom-up PRP calculations of the total radiative anomalies, i.e the sum of all the individual (x_i) PRP calculations:

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- Compute metrics for (1) global mean time series, (2) regional [1x1 degree] time series
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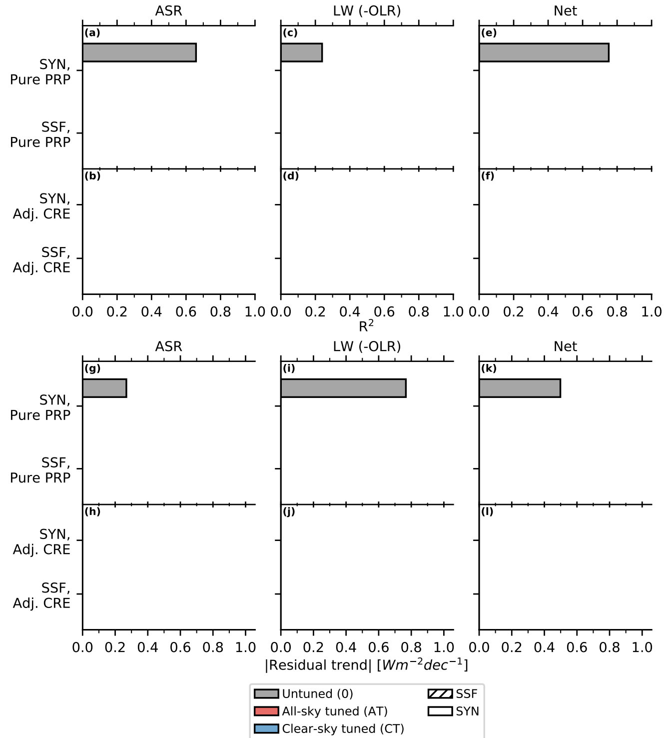
- Make comparisons for PRP calculations based on the various combinations of:
  1. Cloud inputs: SYN, SSF
  2. EBAF-surface tuned inputs: untuned (0), all-sky tuned (AT), clear-sky tuned (CT)
  3. Approach for isolating clouds anomalies: pure PRP, adjusted CRE

Variability closure
(global mean time series)



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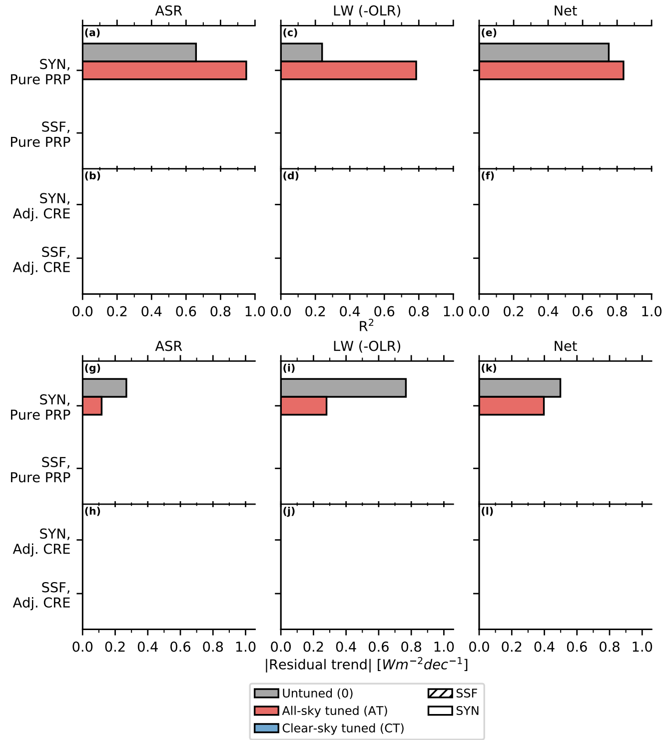

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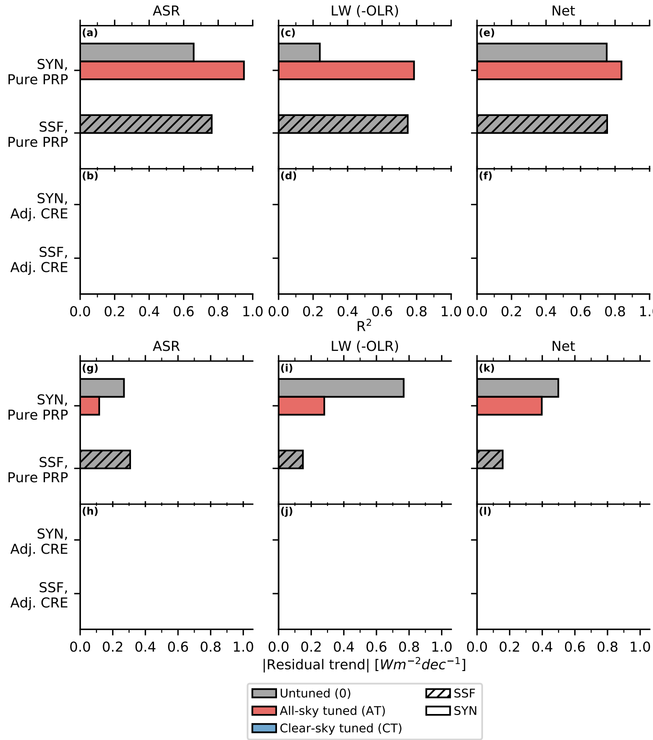

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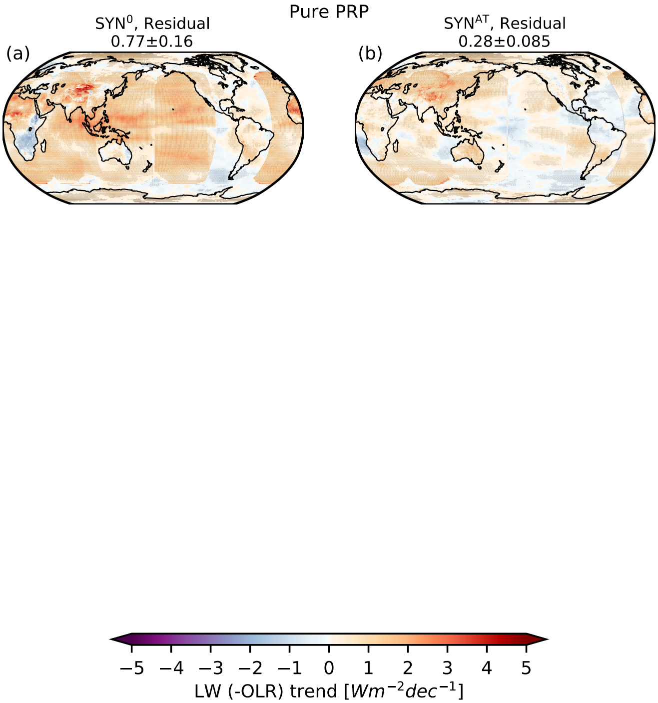
- SSF^0: mostly better comparisons than SYN^0, but not better than SYN^{AT}

Impact of all-sky tuning (i.e. insight into EBAF-surface algorithm)

- (a) $\rightarrow$ (b): geostationary artifacts greatly reduced in the residual trends (EBAF-surface algorithm is improving agreement to EBAF-TOA)



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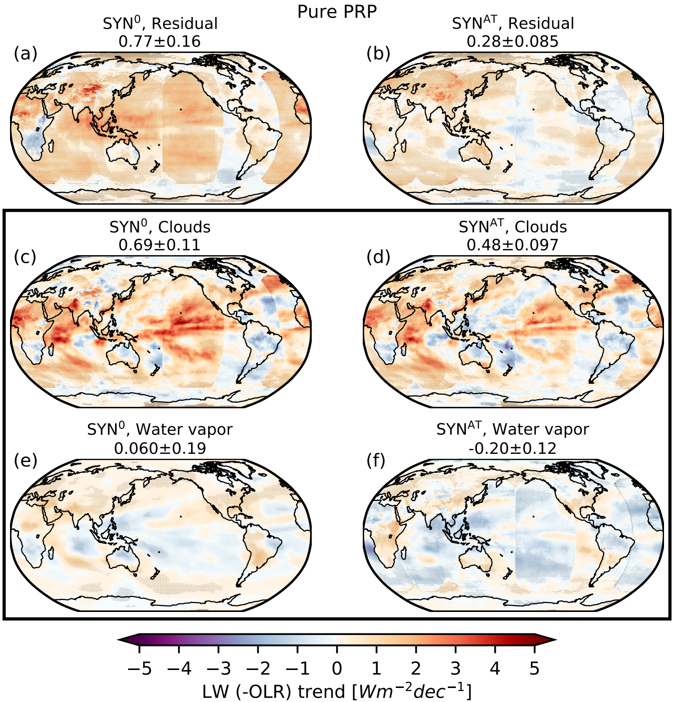

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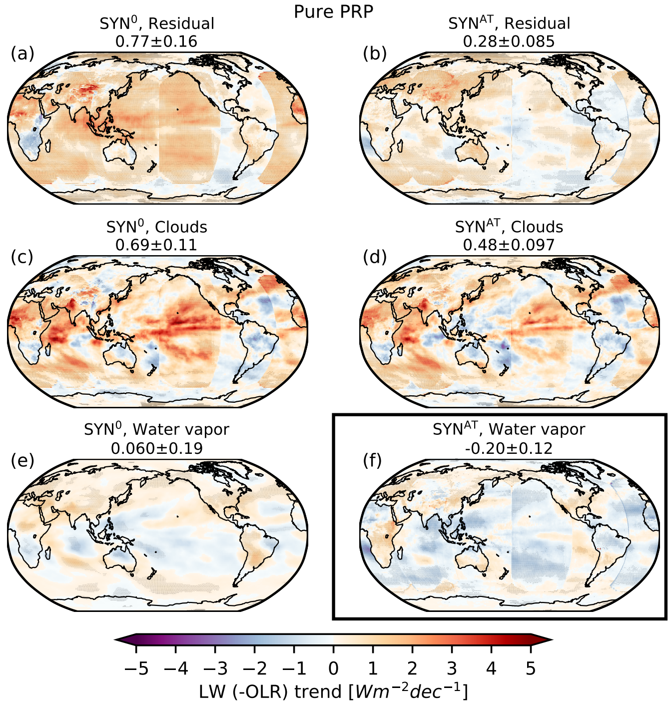
- (a) → (b): geostationary artifacts greatly reduced in the residual trends (EBAF-surface algorithm is improving agreement to EBAF-TOA)
- This reduction in the residual trend is mostly achieved by adjusting the cloud properties and water vapor
- However, the water vapor radiative trends in SYN^{AT} (f) have geostationary artifacts
- EBAF-surface algorithm is erroneously adjusting the water vapor to compensate for uncertainties in the cloud properties → best to avoid using all-sky tuned inputs



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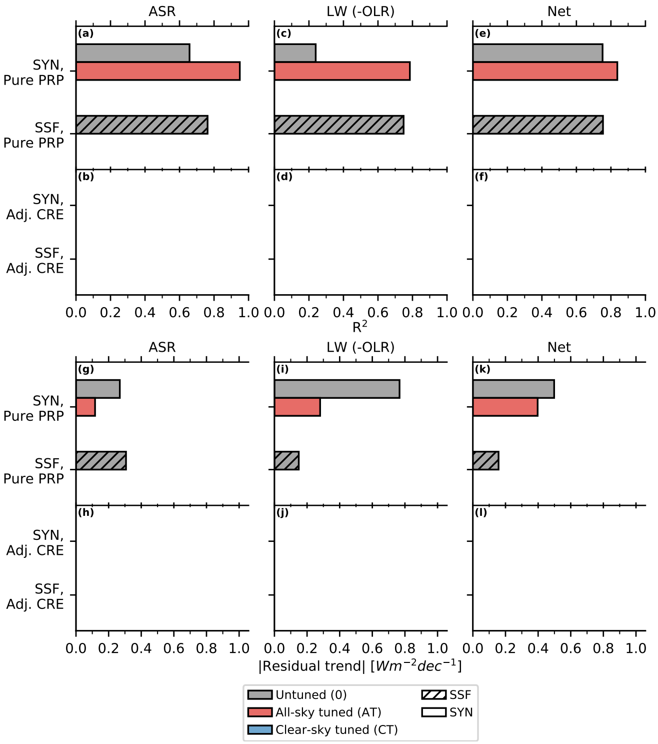
Pure PRP ($\delta F^{PRP}_{\Delta cld}$):

- Avoid SYN^{AT}, but can still leverage clear-sky tuned inputs



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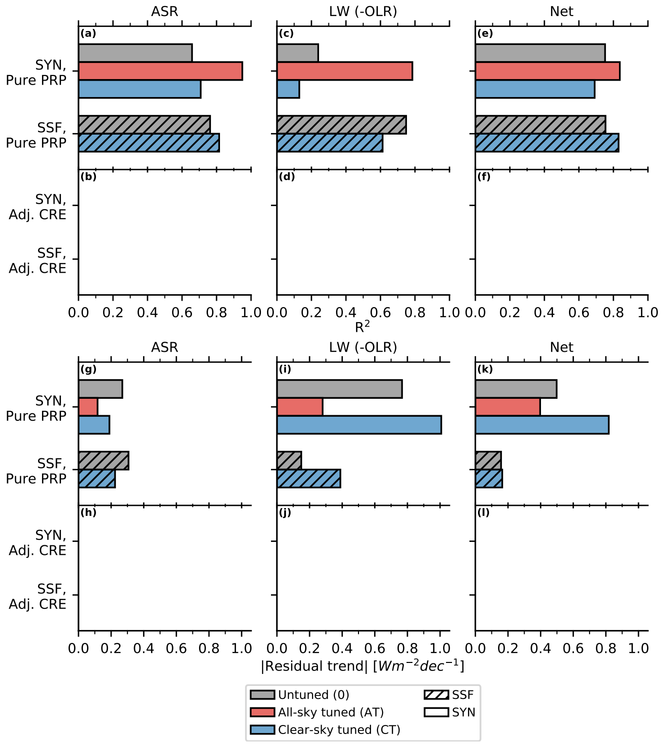

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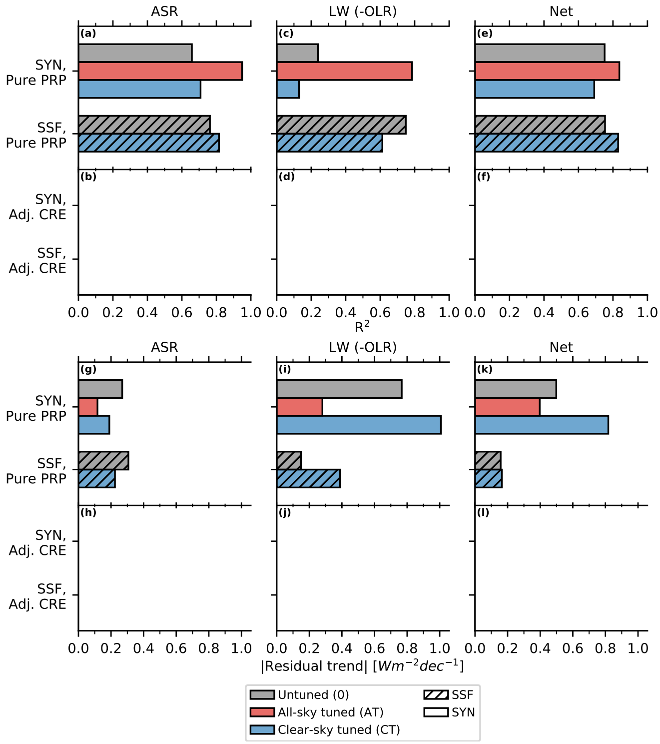

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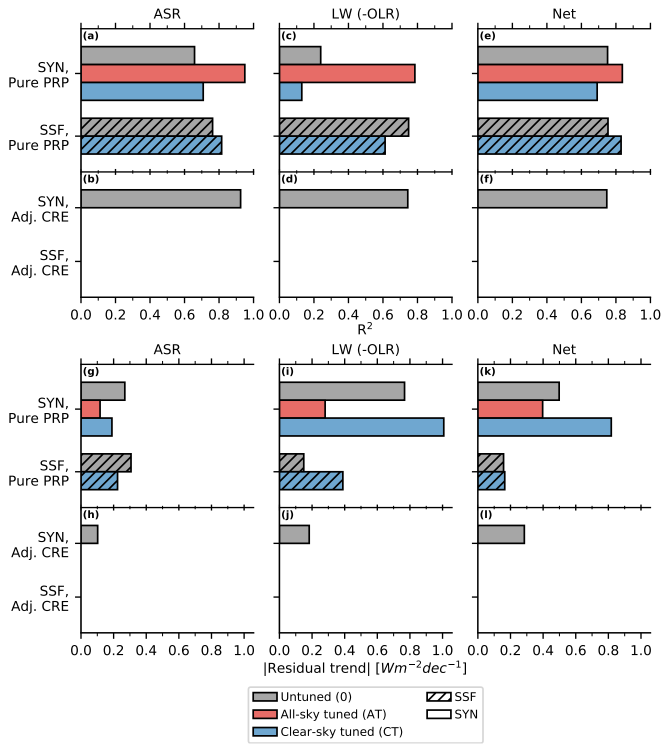

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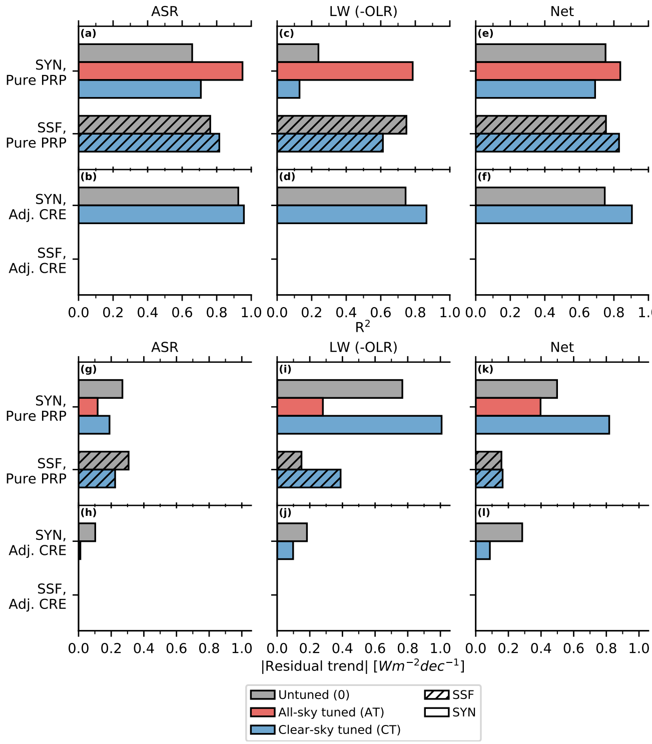

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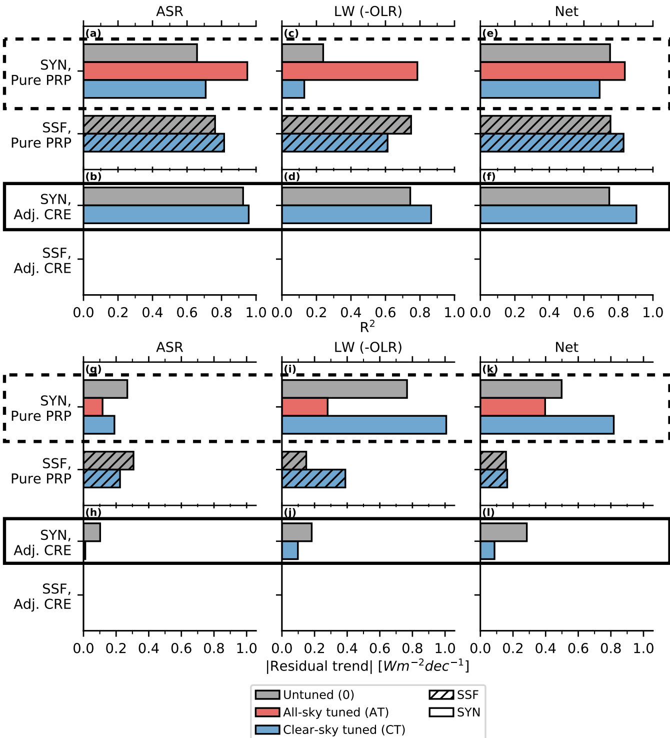

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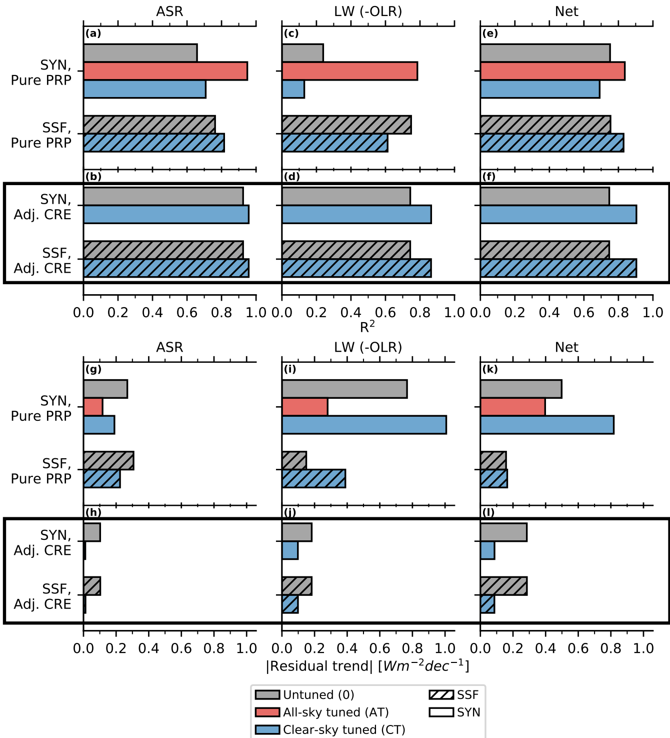

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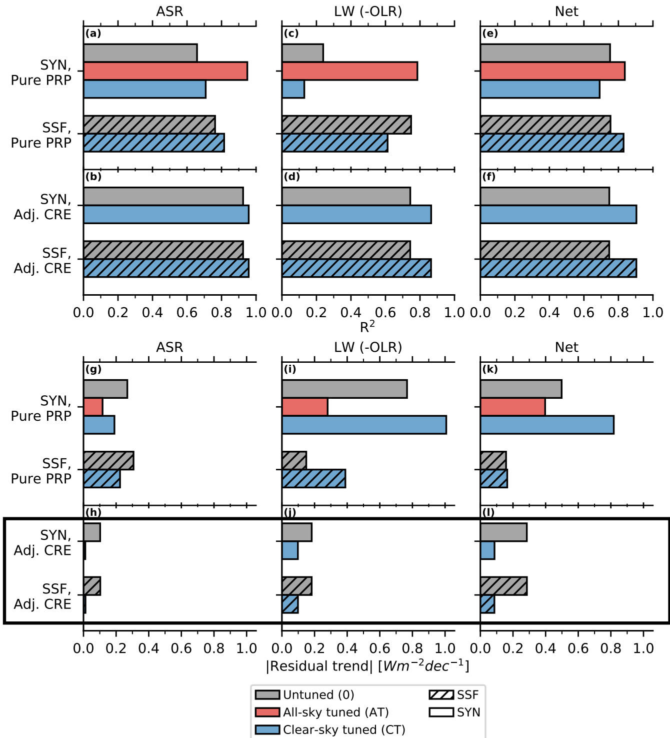

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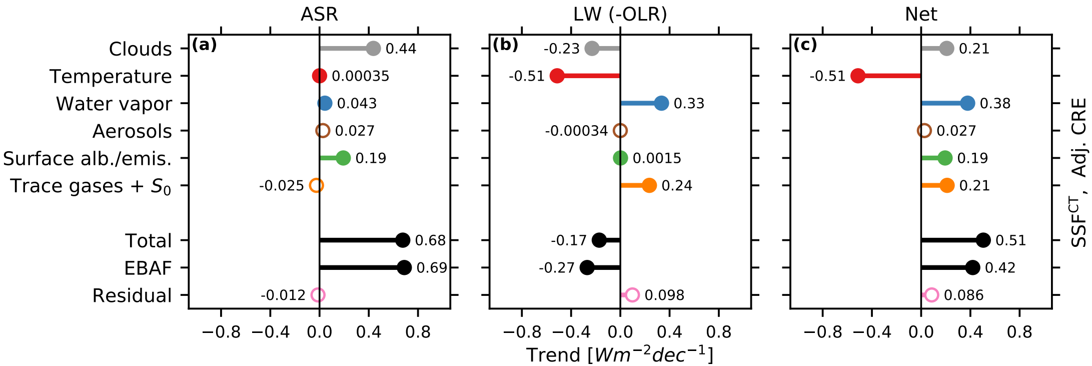
To decompose the energy budget, it is best to use calculations based on SSF cloud properties, clear-sky tuned inputs, and the adjusted CRE approach to isolate cloud anomalies.

Attribution



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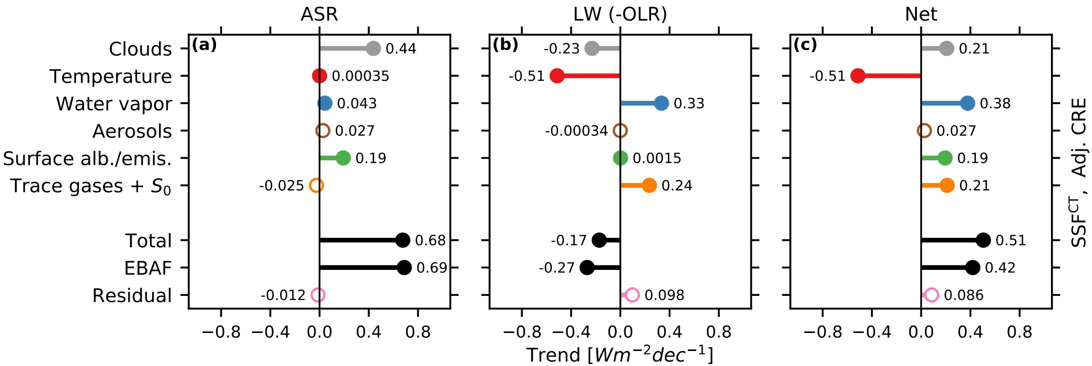

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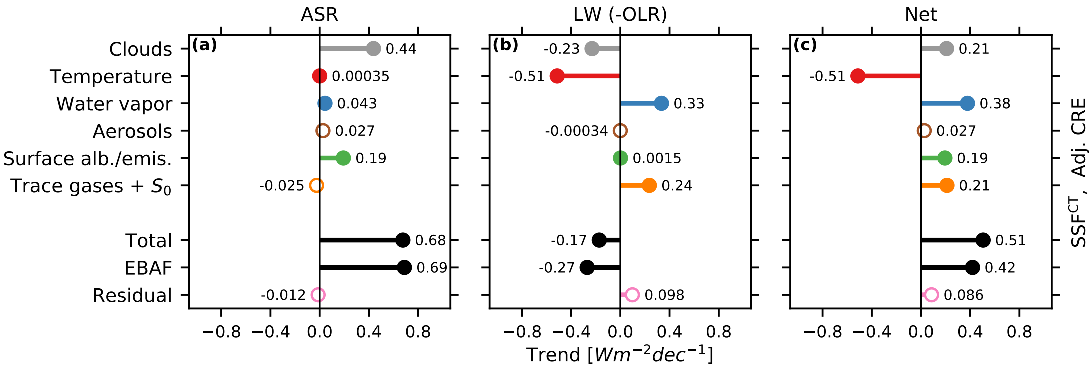

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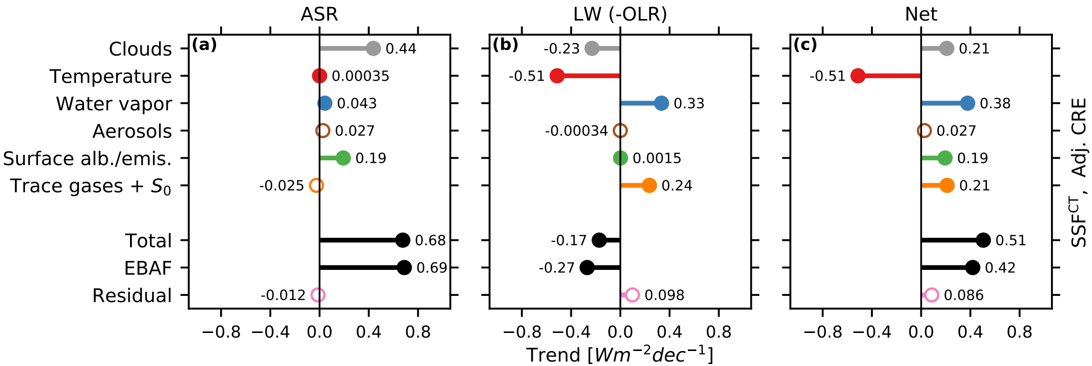

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- (c) Positive net trend with the underlying changes all contributing significantly with the exception of aerosols. Negative contribution from temperature is overwelmed by the positive contributions from clouds, water vapor, surface albedo, and trace gas changes.